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SUBMARINE STRUCTURAL ANALYSIS SUITE SUBSAS PHASE 1

N.G Pegg
D.C Heath

Defence R&D Canada

Technical Memorandum
DREA TM 2001-025
March 2001

National Defence Défense nationale

Canada

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Submarine Structural Analysis Suite SubSAS Phase 1

N.G. Pegg
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Defence Research Establishment Atlantic

Technical Memorandum

DREA TM 2001 –025

March 2001

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Abstract

This technical memorandum describes the current development of, and future plans for, a 'smart' user interface which is being used to unite a suite of submarine structural analysis programs. The project is making use of object-oriented programming through DREA's HOOD TK (Hierarchical Object Oriented Developers Tool Kit) for the development and use of 'smart-object-models' (SOM) for submarine structure. The program allows the user to quickly generate a common database of axisymmetric and 3D pressure hull geometry SOMs. Pressure hull analysis programs will consist of linear axisymmetric analysis, analytical design-type equations, and linear and nonlinear 3D finite element analysis. The SOMs will have the ability to directly and quickly create appropriate input data files for these different analysis packages from the common pressure hull geometry database. A set of model checking and result visualization tools are also being developed to visualize buckling and vibration eigenvalues and mode shapes, displacements and stress contours.

This submarine structural analysis suite (SubSAS) will give engineers a tool for rapidly developing models and storing data for various types of analysis which may be required for design, acquisition and through-life support of submarines.

Résumé

Cette notice technique décrit les plans futurs et les travaux en cours en vue de l'élaboration d'une interface-utilisateur « intelligente » utilisée pour réunir une suite de programmes existants d'analyse structurale des sous-marins. Le projet fait appel à une programmation orientée objet en se servant de HOOD TK (boîte à outils hiérarchique orientée objet pour développeurs) du CRDA pour élaborer et utiliser des « modèles objets intelligents » (MOI) de la structure des sous-marins. Le programme permet à l'utilisateur de produire rapidement une base de données commune de MOI de géométrie de coque épaisse axisymétriques et tridimensionnels. Les programmes d'analyse de coque épaisse comprendront des analyses linéaires axisymétriques, des équations analytiques et des analyses par éléments finis tridimensionnelles linéaires et non linéaires. Les MOI peuvent créer directement et rapidement les fichiers de données d'entrée appropriés pour ces différents progiciels d'analyse à partir de la base de donnée commune de géométrie de coque épaisse. Un ensemble d'outils de vérification des modèles et de visualisation des résultats en cours de développement permettront de visualiser les valeurs propres des déformations et des vibrations et les profils de formes du mode, de déplacements et de contraintes.

La suite pour analyse structurale des sous-marins (SubSAS) fournira aux ingénieurs un outil rapide leur permettant d'élaborer des modèles et de stocker des données pour divers types d'analyses pouvant être nécessaires pour la conception, l'acquisition et l'entretien en service des sous-marins.

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Executive summary

Introduction

Various structural analysis capabilities are required for design, acquisition and in-service support of submarines. For the Canadian Department of National Defence (DND), an in-house capability for the analysis of pressure hull and secondary structure integrity is necessary to assess changes from damage and in-service degradation, or from re-configuration to address design modifications for operational requirements.

This technical memorandum describes the plans and current development of a 'smart' user interface which is being used to unite a suite of existing submarine structural analysis programs. The project is making use of object-oriented programming through DREA's HOOD TK (Hierarchical Object Oriented Developers Tool Kit) for the development and use of 'smart-object-models' (SOM) for submarine structure. The program allows the user to quickly generate a common database of axisymmetric and 3D pressure hull geometry SOMs. Pressure hull analysis programs will consist of linear axisymmetric analysis, analytical design-type equations, and linear and nonlinear 3D finite element analysis, all of which have been used at DREA for submarine structural analysis in the past. The SOMs have the ability to directly and quickly create appropriate input data files for these different analysis packages from the common pressure hull geometry database. A set of model checking and result visualization tools are also being developed to visualize buckling and vibration eigenvalues and mode shapes, displacements and stress contours.

The work has been and will be done jointly through in-house and contract work, with resources being derived from in-house efforts, technology investment funds, possibly technology application funds and involvement (including expected cash contributions) of international partners.

Principal Results

The main goal of this present work is to make a wide range of submarine analysis packages easily available to the user through a common 'smart' user interface and database. This will give the engineer an extensive and sophisticated tool for undertaking rapid assessment of the structural capability of submarine pressure hulls. This phase 1 development of SubSAS is limited to developing a geometric model of the axisymmetric pressure hull and undertaking linear axisymmetric stress and buckling analysis. The inclusion of modelling wizards has resulted in a tool whereby the user can produce a geometric model of a complex ring-stiffened pressure hull with varying diameter, thicknesses and stiffener scantlings in a few minutes and undertake an analysis also in only a few minutes. This represents an improvement in time from several hours for a user knowledgeable with the submarine and analysis package. The improvement would be greater for an inexperienced user who would otherwise have to become familiar with the analysis package in order to produce the input data files. A

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plan for continuing a phase 2 development which will include the full three-dimensional pressure hull and secondary structure such as cutouts, decks, tanks, etc and allow a range of analysis options from linear axisymmetric to three-dimensional elasto-plastic collapse has been developed and is discussed in this report. It is expected that speed of analysis for full three-dimensional nonlinear analysis will improve from several days or even weeks to a couple of hours.

Significance of Results

This represents the initial work in developing and using the Smart Object Modelling technology which showed significant advantages in creating expert system types of user interfaces. The SOM Wizard interfaces guide the user through creation of the geometric model. Once this geometric model is created, it can be used to produce a variety of analysis models, again with the program assisting the user in proper selection of analysis parameters. This feature means that a user does not have to be completely familiar with the analysis programs and their data input files which are being used. This is especially important for engineering staff who have a wide range of responsibilities and do not have the time to maintain sufficient familiarity with software tools which are used on an occasional basis.

The phase 1 SubSAS developments have been demonstrated to our allies who have indicated that they are interested in providing financial support and contributing submarine structures analysis programs to the phase 2 development.

Future Plans

This report outlines plans for development of phase 2 of SubSAS. This will provide a comprehensive set of modelling and structural analysis tools for normal operations of a submarine. Following phase 2, a third phase to address specialized loading such as ice loads, wave loads and loads from weapons will be considered.

Pegg, N. G., Heath, D. (2001). Submarine Structural Analysis Suite (SubSAS) Phase 1. (TM 2001-025). Defence Research Establishment Atlantic.

Sommaire

Introduction

Plusieurs outils d'analyse structurale sont requis pour la conception, l'acquisition et l'entretien en service des sous-marins. Le ministère de la Défense nationale du Canada (MDN) a besoin d'un outil maison d'analyse de l'intégrité de la coque épaisse et des structures secondaires pour évaluer les changements causés par des avaries et par la détérioration en service ou par une reconfiguration visant à modifier la conception pour répondre aux besoins opérationnels.

Cette notice technique décrit les plans futurs et les travaux en cours en vue de l'élaboration d'une interface-utilisateur « intelligente » utilisée pour réunir une suite de programmes existants d'analyse structurale des sous-marins. Le projet fait appel à une programmation orientée objet en se servant de HOOD TK (boîte à outils hiérarchique orientée objet pour développeurs) du CRDA pour élaborer et utiliser des « modèles objets intelligents » (MOI) de la structure des sous-marins. Le programme permet à l'utilisateur de produire rapidement une base de données commune de MOI de géométrie de coque épaisse axisymétriques et tridimensionnels. Les programmes d'analyse de coque épaisse comprendront des analyses linéaires axisymétriques, des équations analytiques et des analyses par éléments finis tridimensionnelles linéaires et non linéaires, qui ont toutes déjà été utilisées au CRDA pour l'analyse structurale des sous-marins. Les MOI peuvent créer directement et rapidement les fichiers de données d'entrée appropriés pour ces différents progiciels d'analyse à partir de la base de donnée commune de géométrie de coque épaisse. Un ensemble d'outils de vérification des modèles et de visualisation des résultats en cours de développement permettront de visualiser les valeurs propres des déformations et des vibrations et les profils de formes du mode, de déplacements et de contraintes.

Les travaux continueront d'être effectués à l'interne et par contrats, avec des ressources provenant du ministère, de fonds d'investissement technologique, et possiblement de fonds d'applications technologiques et de partenaires internationaux (contribution financière prévue).

Principaux résultats

Le but principal du projet est de mettre à la disposition des utilisateurs une vaste gamme de progiciels d'analyse de sous-marins à travers une interface utilisateur « intelligente » et une base de données communes. Cet outil complet et perfectionné permettra aux ingénieurs d'effectuer une évaluation rapide de la capacité structurale des coques épaisses de sous-marins. L'étape 1 du développement du SubSAS se limite à l'élaboration d'un modèle géométrique de coque épaisse axisymétrique et à effectuer des analyses linéaires et axisymétriques des contraintes et flambage. L'ajout de guides de modélisation a permis d'obtenir un outil permettant à l'utilisateur de produire un modèle géométrique d'une coque épaisse complexe à renforts annulaires de diamètres,

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épaisseurs et renforts variables en quelques minutes et d'en effectuer l'analyse aussi en quelques minutes. L'économie de temps réalisée peut être de plusieurs heures pour un utilisateur qui connaît bien le sous-marin et le progiciel d'analyse et de beaucoup plus pour un utilisateur inexpérimenté qui auparavant aurait du se familiariser avec le progiciel d'analyse avant de pouvoir produire les fichiers de données d'entrée. Un plan a été élaboré pour passer à l'étape 2 du développement qui comprendra l'analyse tridimensionnelle complète de la coque épaisse et des structures secondaires comme les découpures, les ponts, les citernes, etc. et fournira différentes options d'analyse, de l'analyse linéaire axisymétrique à l'analyse tridimensionnelle de l'affaissement élastoplastique. Cette étape est traitée dans cette étude. Il est prévu que la vitesse d'analyse pour l'analyse non linéaire tridimensionnelle complète passera de plusieurs jours ou même plusieurs semaines à quelques heures.

Importance des résultats

Ce rapport traite des premiers travaux d'élaboration et d'utilisation de la technologie des modèles objets intelligents qui présente divers avantages pour la création d'interfaces-utilisateurs de type système expert. Les interfaces guides de modélisation orientent l'utilisateur dans la création du modèle géométrique. Lorsque ce modèle géométrique est créé, il peut servir à produire divers modèles d'analyse, le programme l'aidant aussi à bien choisir ses paramètres d'analyse. Cela signifie que l'utilisateur n'a pas a avoir une connaissance approfondie des programmes d'analyse et des fichiers de données d'entrée utilisés. Cette caractéristique est particulièrement importante pour le personnel technique qui a diverses responsabilités et qui n'a pas le temps de bien se familiariser avec les logiciels utilisés de façon occasionnelle.

L'étape 1 de l'élaboration du SubSAS a été présentée à nos alliées qui se sont montré intéressés à apporter un soutien financier et à fournir des programmes d'analyse de structures de sous-marins en vue de l'étape 2.

Plans futurs

Ce rapport présente les plans de l'étape 2 de l'élaboration du SubSAS. Cette étape permettra de créer un ensemble complet d'outils de modélisation et d'analyse structurale pour assurer le fonctionnement normal d'un sous-marin. Suite à l'étape 2, une troisième étape portant sur les charges spéciales comme les charges causées par la glace, les vagues et l'armement sera prise en compte.

Pegg, N. G., Heath, D. (2001). Suite pour analyse structurale des sous-marins (SubSAS) Étape 1. (DT 2001-025). Centre de recherches pour la défense (Atlantique).

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1. Introduction

Various structural analysis capabilities are required for design, acquisition and in-service support of submarines. For the Canadian Department of National Defence (DND), an in-house capability to assess the base-line structural integrity of acquired submarines, and more importantly, to assess changes to the structure during life, is necessary. The pressure hull is the main target of submarine structural analysis, although assessment of secondary structure is also occasionally required. In-service structural assessment of the pressure hull may be necessary to assess changes from damage and in-service degradation, or from re-configuration to address design modifications for operational requirements.

Through the 1980's and early 1990's DREA's Structural Mechanics group undertook a program to develop and validate software tools for the analysis of submarine structures. This was done to support CASAP (Canadian Submarine Acquisition Program) and ongoing support of the Oberon class. Many of these tools were incorporated into a suite of programs called SVAST [1]. SVAST undertook linear finite element analysis of submarine pressure hulls and included some additional analytical codes, based on classical design equations, which were produced directly by DREA [2] or were acquired through exchange agreements. Developments to support nonlinear finite element collapse analysis of 3D models were also initiated. A research program consisting of advanced analysis and experiments on model submarine pressure hulls was undertaken to validate the various analysis programs, particularly those for predicting nonlinear elasto-plastic collapse [3,4].

The CASAP program was postponed and DREA's work in submarine structures was reduced to a minimal level through most of the 1990's. With the recent decision to purchase the VICTORIA class, there is renewed interest in DREA and DND, to have the necessary analysis tools available to support the life cycle management of the pressure hull. Work has recently begun to address the resurrection and testing of SVAST and other advanced analysis codes and to develop these within a modern computer programming environment.

While the work on submarine structures saw little progress through the 1990's, development of a suite of codes to address ship structures saw extensive development. The DSA (Detail Stress Analysis) [5] code is jointly owned and developed by DREA and Martec Ltd of Halifax, Nova Scotia. DSA has been developed to allow efficient global and detail finite element analysis of ship structure [6,7]. DSA is also being used as a central driving engine for a number of specialized ship related analysis programs for wave loads, ultimate strength, mast analysis, fatigue assessment, UNDEX and

others. A recent development has been the production of a set of object oriented modelling tools for ship structure. This new technology, entitled HOOD tk (Hierarchical Object-Oriented Developers tool kit) allows the rapid production of structural and other analysis models within an advanced computing environment. The efforts in developing the submarine analysis suite (SubSAS) are making use of some of the specialized features and operating environment of the DSA program and the HOOD tool kit.

The main goal of this present work is to make a wide range of submarine analysis packages available to the user through a common user interface and database. This will give the engineer an extensive and sophisticated tool for undertaking rapid assessment of the structural capability of submarine pressure hulls. The development has been divided into two phases. Phase 1of SubSAS is complete and consists of the basic HOOD and SOM framework for axisymmetric pressure hull geometry generation and linear axisymmetric analysis capabilities. Phase 2 is in the planning stages and addresses non-axisymmetric submarine structure and three-dimensional linear and nonlinear finite element analysis. The initial resources for phase 1 of this work came from in-house efforts and technology investment funds. Technology application funds and collaboration (including expected cash contributions) with international partners are being sought for the phase 2 developments.

This memorandum first describes the requirements for a submarine structural analysis suite and then discusses the approach used in developing an integrated program design. The specifics for the submarine geometry generation are then described followed by a review of the analysis programs that have been and will be incorporated into SubSAS. The typical types of analysis results for submarine structures derived from these analysis programs and how SubSAS displays them to the user are presented. An example application of the Phase 1 SubSAS program is included to serve as a user's manual. Finally a discussion of plans for the Phase 2 development and concluding remarks are presented.

2. REQUIREMENTS FOR SUBMARINE STRUCTURAL ANALYSIS

While submarines require much the same types of analyses as other structures, their integrity assessment is dominated by the hydrostatic pressure load which produces a primary compressive stress state and the possibility of buckling instability failure. The main load carrying structure is the pressure hull consisting of axisymmetric ring-stiffened shell compartments, transverse bulkheads and dome ends. Secondary structure such as decks, tanks, penetrations, towers and hull casings also require analysis and their interaction with, and effect on, the main pressure hull components must be considered. Buckling instability is sensitive to geometric shape imperfections so that considerable care must be taken in the design, building, maintenance and analysis of a submarine pressure hull.

Basic pressure hull analysis has been accomplished in the past using reasonably simple analytical models for pressure hulls, coupled with extensive test data and empirically derived safety factors. Recent advances in computing power have made it possible to model the complex elasto-plastic collapse behaviour of a pressure hull including the effects of imperfections and secondary structure. A combination of the various available analytical and numerical methods and models is the most appropriate approach to analyzing submarine structure.

2.1 Requirements for Pressure Hull Analysis

The pressure hull (shown in Figure 1) consists of internal and external ring-stiffened cylinders and cones, endcaps, and bulkheads. The pressure hull structure can be influenced by connections to decks and tanks and by discontinuities produced by penetrations such as hatches and torpedo tubes.

Analysis consists of determining stress and buckling limits. Stress analysis is done to ensure that material yielding does not occur and to ensure that fatigue limits are not reached through the cyclic loads produced by diving and surfacing. Including the effects of fabrication residual stresses is essential for fatigue analysis as these produce the tension stresses in the shell frame intersections where fatigue failure can occur.

The critical buckling modes of the pressure hull are of two main configurations; overall compartment buckling, and local interframe buckling. Overall compartment buckling usually occurs in modes of a half sine wave over the compartment length and 2 to 4 waves around the cylinder circumference. The effects of out-of-circularity imperfections in the shell, and in particular, the ring-stiffeners, is significant in determining overall buckling collapse loads. Major transverse bulkheads generally define compartments, but overall modes may involve more than one continuous compartment. Interframe buckling initiates locally over a single or a few frame spaces.

The interframe buckling mode consists of a half sine wave over the frame spacing length and several (typically 12-18) waves around the circumference. Figure 2 shows the overall and interframe buckling mode shapes. In cases where the overall and interframe buckling loads are of similar value, a combined overall-interframe buckling model can occur which may be the lowest valued, critical, buckling load. Shape imperfections which cause deviations from a perfect circular shape can significantly reduce the critical submarine collapse pressure. It is necessary to assess the geometry of the pressure hull and to use analysis methods that include the effects of shape imperfections, or out-of-circularity, in the collapse calculations.

Vibration analysis is also an important consideration for submarines, usually more for its role in defining acoustic signature than for structural integrity. Accurate mass descriptions as well as the stiffness properties of the pressure hull and secondary structure are required for accurate vibration analysis. The effect of the surrounding fluid mass on the calculation of vibration eigenvalues needs to be modelled.

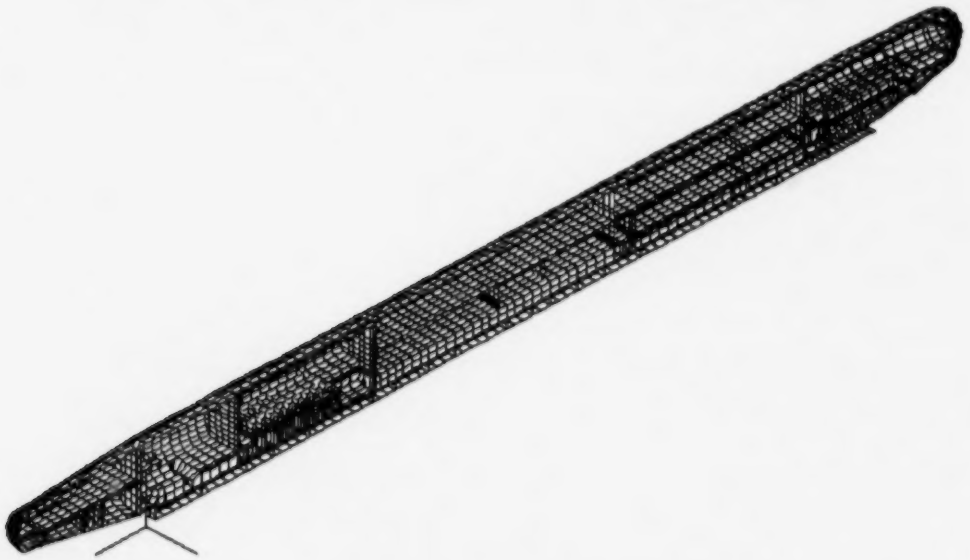


Figure 1: ***Submarine Pressure Hull Finite Element Model (Tanks and Decks Included)***

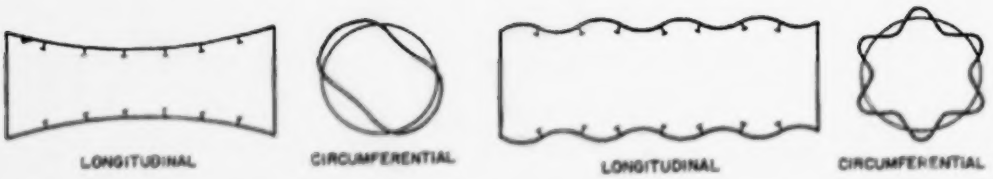


Figure 2: ***Overall and Interframe Buckling Collapse Mode Shapes***

2.2 Requirements for Secondary Structure Analysis

Secondary structure includes the hydrodynamic casing and support frames, the keel, internal and external tanks, control surfaces, decks, escape towers, torpedo tubes and other penetrations. Figure 3 shows some examples of secondary structure internal and external to the pressure hull. Secondary structure must be analyzed for its own stress, buckling, and vibration characteristics and for its interaction with the pressure hull. 'Hard points' which cause increased local stress, or 'nodes' which influence buckling mode shapes, can result at the attachment of secondary structure to the pressure hull.

Figure 3: ***Examples of Secondary Structure Finite Element Models (Decks, Tanks, Keel)***

2.3 Load Requirements

The primary load on submarine structure is hydrostatic pressure from operating at depth. While this is considered a static load, the cyclic nature of the dive operations must be considered for assessing fatigue characteristics. Other types of loads may include surface wave loads, loads from penetrating ice, and weapons loading (underwater explosions). Some of these, particularly weapons loading, may require dynamic analysis.

2.4 Summary of Requirements

The integrated software suite has to consider the following requirements:

1. allow the user to efficiently enter pressure hull and secondary structure geometric and material data;
    - pressure hull structure including ring-stiffened cylinder and conical sections, dome bulkheads of hemispherical, elliptical, torispherical or user defined shape, and transverse stiffened bulkheads with openings, and
    - secondary structure including decks, flat-sided tanks, cylindrical stiffened or unstiffened tanks, cylinder penetrations, reinforced openings, hull casing and support frames, and the keel,
2. allow the user to define the types of analysis that are required including definition of loads;
    - the types of analysis determine stress, displacements, nonlinear collapse loads, buckling loads and vibration frequencies through analytical analysis (classical equations), axisymmetric finite element and finite difference analysis, and linear and nonlinear 3D finite element analysis, and
    - the types of loads include pressure at collapse depth, pressure at operating depth, line and point loads from docking or resting on the bottom, loads from penetrating ice and weapons loads (underwater shock pressure),
3. produce the necessary analysis model or models;
    - axisymmetric finite element models of the pressure hull with variable mesh parameters,
    - axisymmetric finite difference models of the pressure hull with variable mesh parameters,
    - 3D finite element models of the pressure hull with variable mesh parameters,

- analytical models of pressure hull compartments and dome ends, and
- allow importation of existing 'legacy' models,

4. allow the user to efficiently check the numerical or analytical model visually and through numerical model integrity checks;
5. allow the user to choose the program for analysis and efficiently define analysis parameters such as the number of eigenvalues in a buckling analysis or the solution parameters for a nonlinear static collapse analysis;
6. allow the user to input measured or default out-of-circularity values for the pressure hull and frames;
7. provide help and guidance to the user in developing models and analysis parameters;
8. launch the appropriate analysis programs seamlessly;
9. provide visual tools for studying results including;
    - stress contours and deformed shape,
    - buckling and vibration mode shapes,
    - graphs of buckling and vibration eigenvalues,
    - graphs of displacement versus load history for nonlinear collapse analysis, and
    - tables of analytical program results,
10. provide a means to export models and results to reports using Microsoft Office products.

3. APPROACH TO INTEGRATED PROGRAM DESIGN

This section describes the program design approach that has been used in developing the phase 1 production of SubSAS and the extensions that are planned for phase 2.

The program operating environment consists of a graphical user interface (GUI) which calls various functions and graphically displays the operations that are being undertaken by those functions. The Microsoft Foundation Class (MFC) has been used to develop the GUI with the Open Graphics Language (OGL) being used for the graphics interface. The GUI includes standard pull down menu items such as File, View and Help and toolbars for undertaking common operations. The basic GUI as it exists in the phase 1 development is shown in Figure 4.

The HOOD tool kit has been used to develop the program functionalities such as model production, graphics operations, launching analysis codes and development of the Smart Object Models (SOMs). A SOM is a programming entity describing a structural quantity such as a deck. The SOM embodies attributes (data) and functions allowing it to produce models and analysis results for itself. SOM data is entered by the user in the form of property sheets. HOOD is written in Visual C++ version 6, makes extensive use of object re-use, and is used across a number of applications in addition to this SubSAS development (for example; ship motion visualization with Vship and mast analysis with MASTSAS).

Analysis programs consist of legacy code, which were developed in Fortran. These are accessed mainly through exchange of data files with the HOOD tool kit system. It is not planned to rewrite the legacy code in object-oriented format. The exchange of data files is through translators which create input data files from the geometric SubSAS database, accept output data files from the legacy codes and create result processing files for the SubSAS postprocessors.

The analysis suite is being developed in phases. The first phase consists of the overall operating GUI and the development of SOMs, and incorporation of programs, for axisymmetric analysis. The second phase will include the development SOMs for secondary structure and the incorporation of programs for 3D linear and nonlinear finite element analysis. A third phase may include the addition of wave loads, ice penetration loads and weapons loads.

The development process will require a considerable test program. This will be done through the development of test cases which exercise the program's functionality.

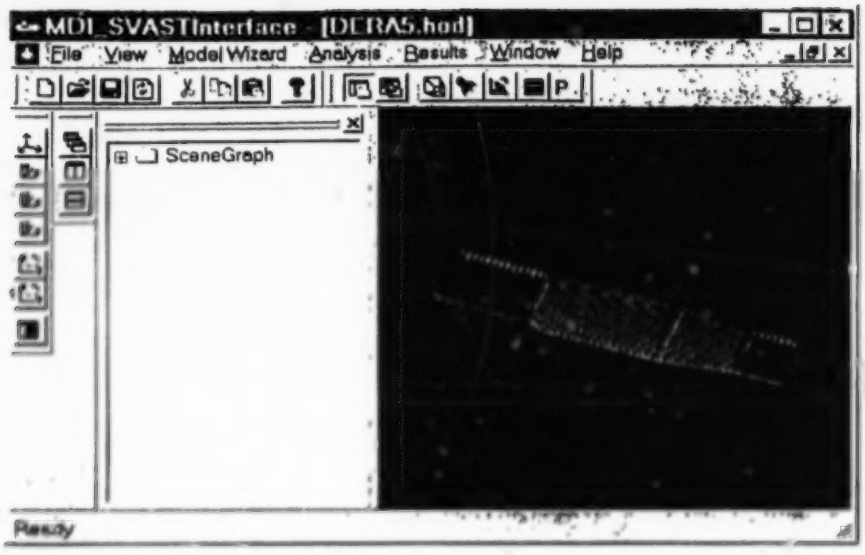


Figure 4 Graphical User Interface (GUI): Current Phase 1 Development of SubSAS

4. SUBMARINE GEOMETRY GENERATION

The creation of the basic submarine geometry is accomplished through the population of SOMs by defining parameter data in property sheets. Property sheets are templates which aid the user in entering the data for the various program requirements including default values which may be used. The property sheets are accessed in several ways through the GUI. A model generation wizard can be used to guide the user through the various property sheets to completely define a model. Alternatively the property sheets can be accessed through a pull-down-menu, clicking on the appropriate data structure in the scene graph or clicking on the actual object on the graphics screen. Editing of existing SOM data is done by changing values in the property files.

4.1 Graphical User Interface (GUI)

Figure 5 shows the phase 1 development GUI and identifies the various means for creating the submarine geometry; the Wizard toolbar item, the Stiffener Generator Scene Graph item, and the stiffener object (outlined by red box) are highlighted. Clicking the left mouse button on the latter two will bring up the stiffener generator property sheet shown in Figure 6. The wizard also brings up the property sheet through instructions to the user. Figure 7 shows the geometry generation wizard. The figure shows the initial page and then the page used to access the stiffener property sheet. Data integrity checks are made by the program, which inform the user that data is missing.

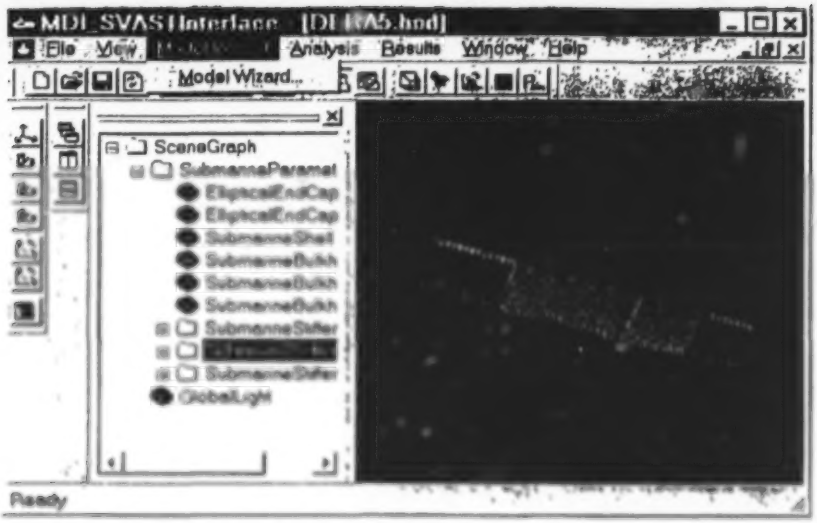


Figure 5. ***Options for SOM Data Entry – Wizard, SceneGraph and Graphics Object***

Figure 6. ***Submarine Stiffener Generator Property Sheet***

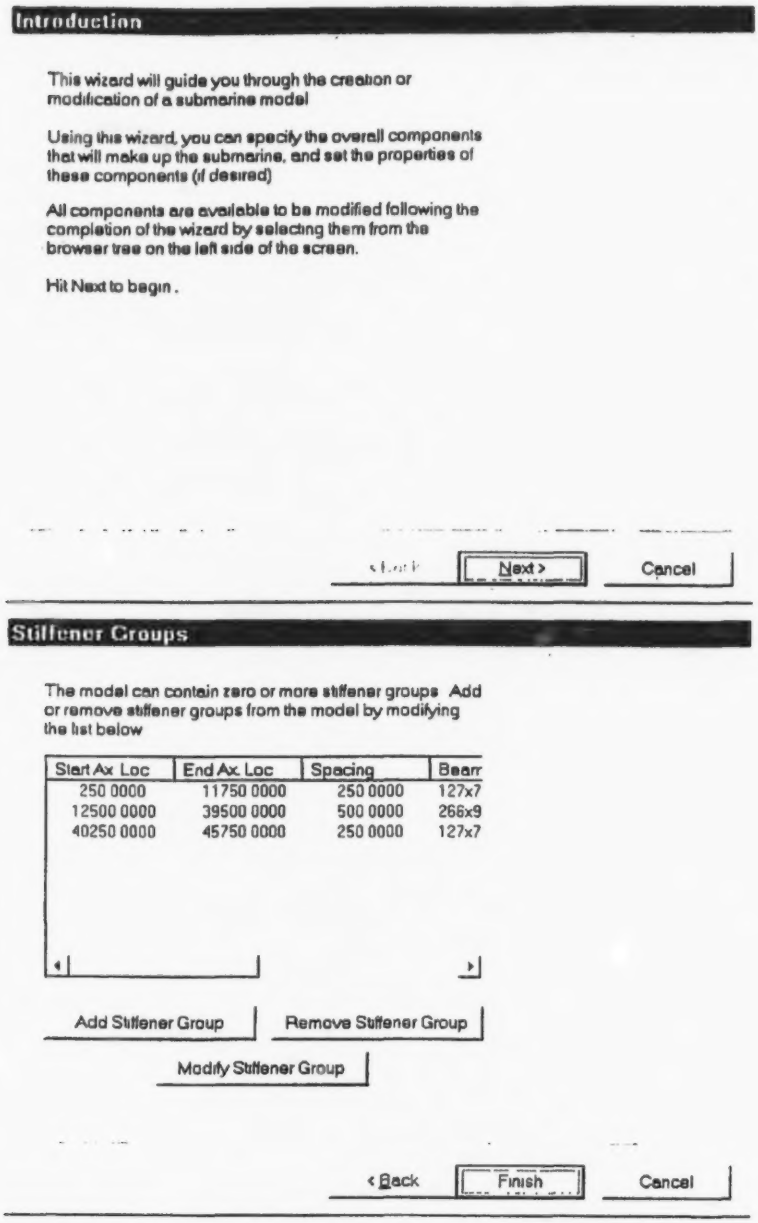
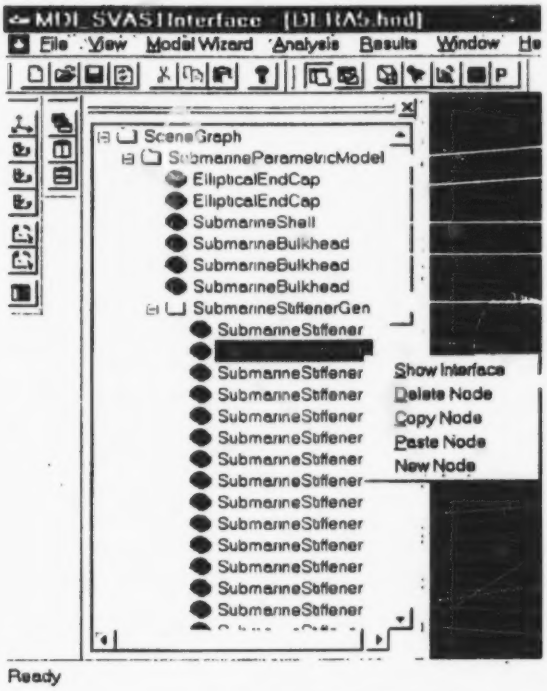

Introduction
This wizard will guide you through the creation or modification of a submarine model
Using this wizard, you can specify the overall components that will make up the submarine, and set the properties of these components (if desired)
All components are available to be modified following the completion of the wizard by selecting them from the browser tree on the left side of the screen.
Hit Next to begin .
< Back
Next >
Cancel
Stiffener Groups
The model can contain zero or more stiffener groups. Add or remove stiffener groups from the model by modifying the list below
Start Ax. Loc
End Ax. Loc
Spacing
Beam
250.0000
11750.0000
250.0000
127x7
12500.0000
39500.0000
500.0000
266x9
40250.0000
45750.0000
250.0000
127x7
Add Stiffener Group
Remove Stiffener Group
Modify Stiffener Group
< Back
Finish
Cancel

Figure 7: Model Generation Wizard Showing Access to the Stiffener Property Sheet

4.2 Hierarchical Object Relations and the Scene Graph

An important aspect of the efficient modelling approach that is being used in SubSAS is the relational aspect of the data objects. A hierarchy is followed such that lower order objects (children) belong to higher order objects (parents). An example of this is a stiffener object which is a child to the shell object. This provides some of the 'smarts' in a SOM as the objects know what higher order objects they belong to and what lower order objects belong to them. This makes the organization of the data efficient and facilitates the attachment of structural objects to other structural objects. The Scene Graph, shown in Figure 8, shows the hierarchical scheme and also provides direct access to the various object property data sheets. Relationships can be changed by dragging and dropping objects in the Scene Graph.



Overall Parent Submarine Object

Endcap Objects

Shell Object

Bulkhead Objects

Stiffener Generator Objects

Operations Allowed on Objects in Scene Graph

Figure 8: The Scene Graph Showing Object Hierarchy

4.3 Smart Object Models (SOM) and Property Sheets

A SOM is a piece of object-oriented code describing a physical object such that it knows what parameters (data) it is supposed to have and where to get them and what functions it is supposed to perform and how to perform them. Again, using the

example of the stiffener as a SOM, the parameters would be the web and flange scantlings, offset, material, type of stiffener, and its location on the shell. The functions would be the ability to populate the parameters with data (perhaps from a beam scantling database), produce various types of FE meshes on itself and perhaps assess its stress results against buckling or stress criteria. The SOM parameters are populated by the use of property sheets, as shown above in Figure 6.

5. ANALYSIS PROGRAMS

SubSAS will include the various types of analysis that DREA has used for submarine structures in the past. The approach being used for development of the software will allow easy addition of other analysis programs. Phase 1 of SubSAS has incorporated the axisymmetric analysis programs.

5.1 Generation of Analysis Models

The various structural SOMs have the ability to produce numerical models of themselves through the property sheets. The type of model depends on the type of analysis programs, which are discussed in the following sections. Default numerical models are produced which should produce good results in most cases. The user has the option of changing these within the SOM property sheets. The geometric data that exists in the SOM is used to produce the analysis models for all of the programs, ie. the user only has to produce the geometric data once through population of the SOMs.

In addition to the numerical model, there may be solution parameters that are also required by the various programs and these are created through a solution property sheet.

5.2 Axisymmetric Analysis

The basic pressure hull structure is primarily of axisymmetric geometry, meaning that it can be described by shells and frames of revolution through a generator line. The main exceptions to axisymmetry in the pressure hull structure are the bulkheads which are orthogonally stiffened plates. In axisymmetric analyses, the bulkheads can be represented by a uniform plate of equivalent thickness. While ultimately a full three-dimensional analysis is required to consider the effects of secondary structure on the pressure hull, an axisymmetric analysis is instructive in assessing its basic stress and buckling characteristics and for comparison to design codes which are often based on simpler axisymmetric, classical analysis methods. Figure 9 shows an axisymmetric model of a pressure hull.

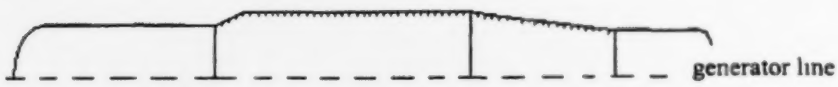


Figure 9: Axisymmetric Model of a Pressure Hull

Axisymmetric analysis is based on using Fourier series harmonics in the circumferential direction and numerical representation through finite element or finite difference models in the longitudinal direction. Buckling and vibration eigenvalues are given in terms of a circumferential harmonic or number of wavelengths, n. Two programs have been used for this and are incorporated in phase 1 of SubSAS. These are the finite element program VAST [8], which has a range of axisymmetric element types, and BOSOR4 [9] which uses a finite difference numerical scheme along the generator length. The VAST axisymmetric finite element analysis also undertakes vibration eigenvalue analysis and allows for the effects of compressive stresses from hydrostatic pressure in the vibration calculations.

The user is given modelling options for the number of axisymmetric shell elements for the endcaps, bulkheads and for the shell between stiffeners, and in the types and numbers of elements to model the ring-stiffeners. Shells, beams or bars may be used to model the stiffeners. The use of shell elements allows for stiffener instability (tripping) to be modelled. The number of elements between ring-stiffeners depends on whether overall buckling or interframe buckling is being sought.

5.3 Analytical (Classical Analysis) Programs

In considering single axisymmetric uniform radii compartments or endcaps of pressure hulls, there have been a number of closed-form expressions developed for stress and buckling analyses. In addition, BS5500 [10] has empirical design curves used for pressure hull and endcap design. Classical analytical equations for uniform ring-stiffened cylindrical pressure vessel compartments and endcaps have been incorporated into a DREA program PRHDEF [2]. Phase 2 of SubSAS will automatically create input files for PRHDEF and allow the user to view the results. The Royal Netherlands Navy analytical program, SUBHUL [11], will also be incorporated into phase 2.

5.4 3D Analysis Programs

Three-dimensional analysis which can account for all of the submarine structure, will be undertaken by finite element analysis (FEA). Linear FEA is used to assess stress states under operational conditions and for determining linear buckling and vibration eigenvalues. Nonlinear FEA is required to model the elasto-plastic collapse behaviour of submarine structure and includes both large deformations and nonlinear material response. The VAST program has all of the requirements to undertake linear and nonlinear FEA of submarine structures. In addition SubSAS will produce data files for ANSYS and any other FEA codes that contributing development partners may wish to use. Figures 1 and 3 showed examples of 3D FEA models of a submarine structure.

6. PRESENTATION OF ANALYSIS RESULTS

The requirements for presentation of results were outlined in the requirements section. For axisymmetric analysis, it is desirable to view the buckling eigenvalues (factors) as a function of circumferential wave number (harmonic). Figure 10 shows such a graph which was developed as part of the phase 1 SubSAS program. The graph shows three eigenvalues per circumferential wavelength where longitudinal variation in mode gives the different eigenvalues. Harmonics 0 and 1 are not used as they do not produce buckling instability modes.

Phase 1 of SubSAS uses some existing components of MGDSA to plot stress and buckling displacements. Figure 11 shows a buckled mode shape of an axisymmetric model rendered into a 3D model to show the displaced shape effectively.

Phase 2 developments of SubSAS will produce all of the analysis viewing options in the HOOD tool kit format operating directly out of the SubSAS shell.

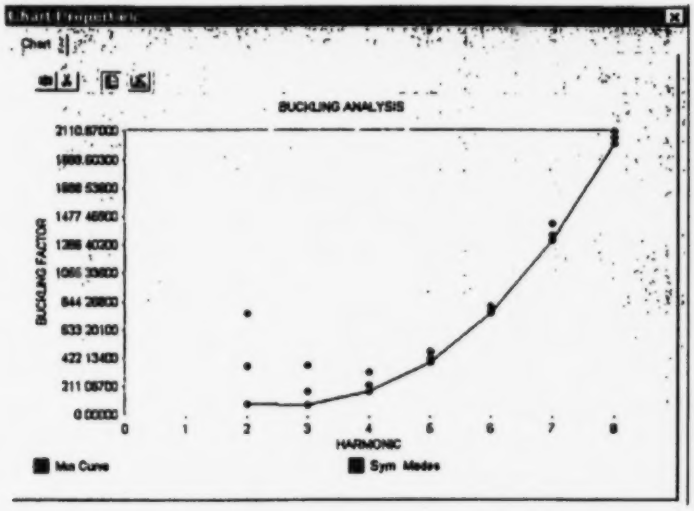


Figure 10: Buckling Eigenvalues versus Circumferential Wave Number (Harmonic) for Axisymmetric Analysis, Phase 1 of SubSAS

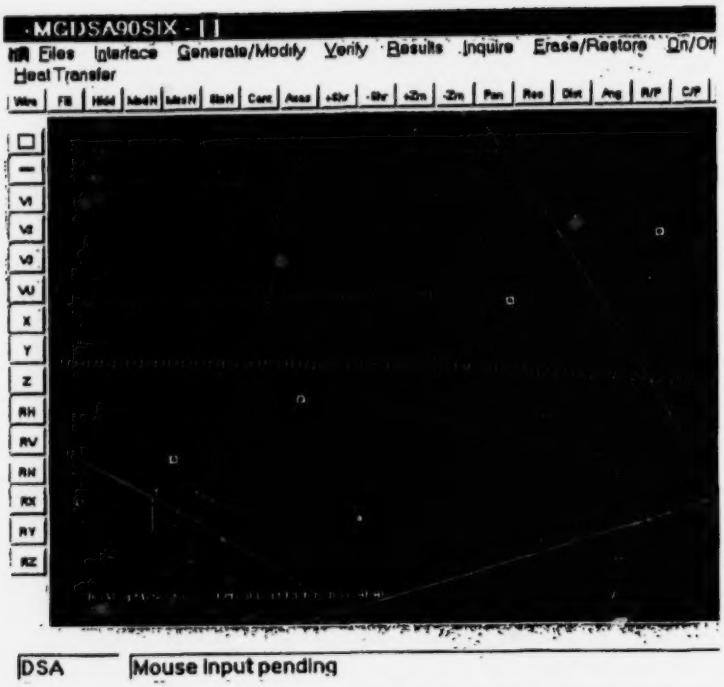
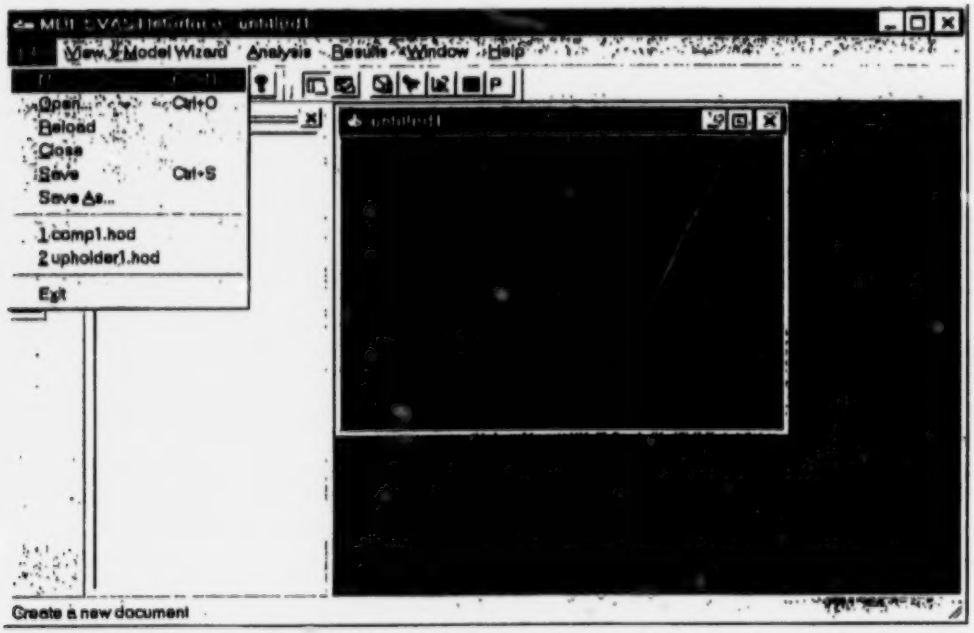


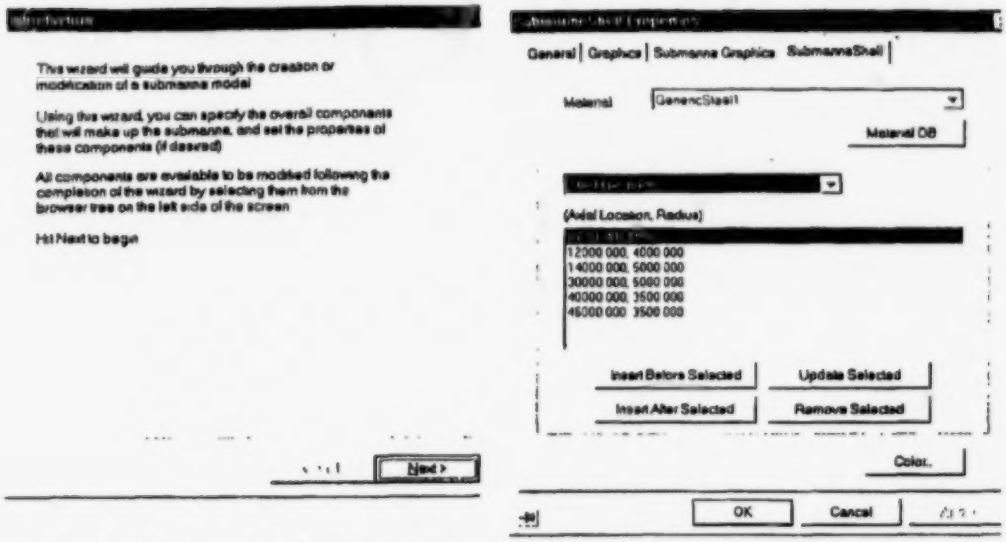
Figure 11: Buckling Mode Shape of Axisymmetric Submarine Pressure Hull Rendered into 3D Model in MGDSA

7. EXAMPLE APPLICATION OF SubSAS

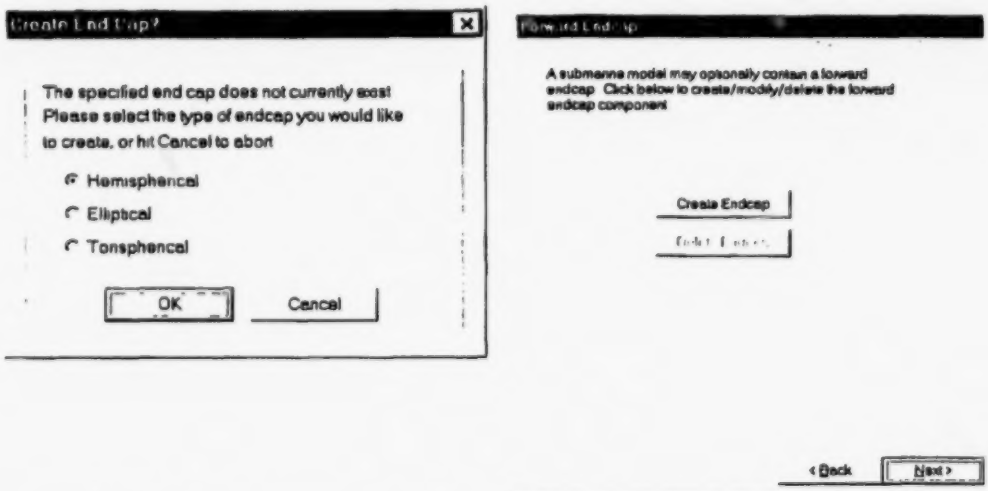
The following series of screen captures and narratives show an example of an axisymmetric pressure hull model being created with Phase 1 of SubSAS and analyzed with the VAST FEA program.



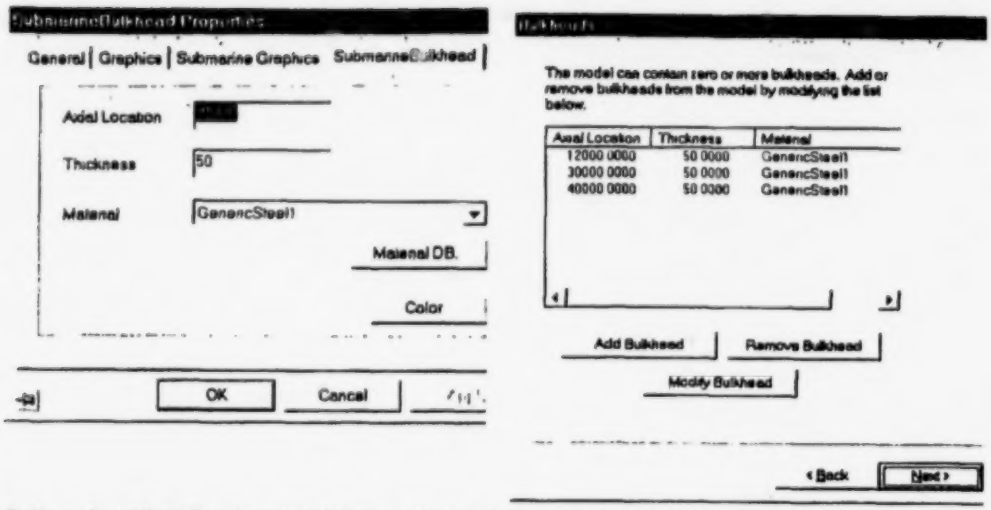
Initiate SubSAS (currently named MDI_SVASTInterface) with the windows application icon and open a new file through the file menu item. Existing data files are shown with the .hod suffix and these may be chosen to run or modify previous analyses. The SubSAS window is brought up with blank graphics and scene graph windows.


This wizard will guide you through the creation or modification of a submarine model
Using this wizard, you can specify the overall components that will make up the submarine, and set the properties of these components (if desired)
All components are available to be modified following the completion of the wizard by selecting them from the browser tree on the left side of the screen
Hit Next to begin
Next >
General | Graphics | Submarine Graphics | SubmarineShell
Material
GenericSteel1
Material DB
(Axial Location, Radius)
12000.000, 4000.000
14000.000, 5000.000
30000.000, 5000.000
40000.000, 3500.000
46000.000, 3500.000
Insert Before Selected
Update Selected
Insert After Selected
Remove Selected
Color...
OK
Cancel

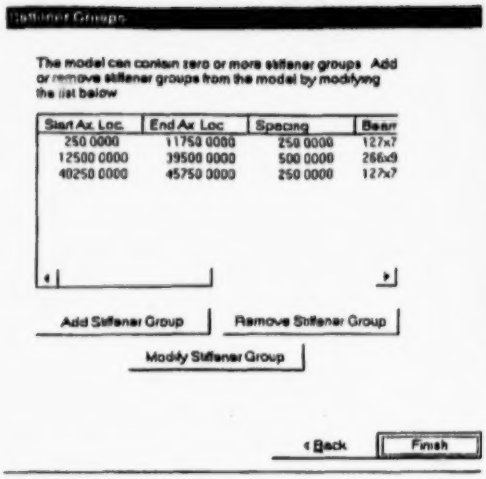
Start the Model Wizard (left) and follow through the instructions to produce the submarine geometry. The property sheet on the right, which is brought up next through the Wizard, shows how to enter the outer shell geometry through axial and radial coordinates. These are placed where there is an initiation or change in geometry.

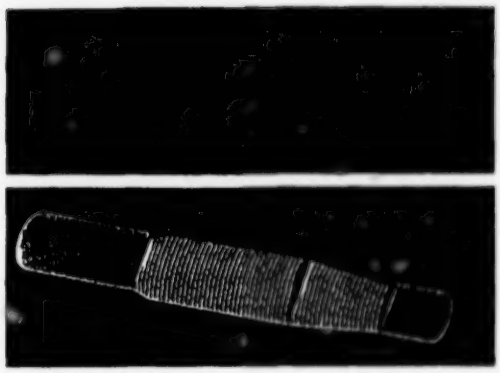

Create End Cap?
The specified end cap does not currently exist
Please select the type of endcap you would like to create, or hit Cancel to abort
Hemispherical
Elliptical
Tonspherical
OK
Cancel
A submarine model may optionally contain a forward endcap. Click below to create/modify/delete the forward endcap component
Create Endcap
< Back
Next >

Follow the Wizard instructions to create the fore and aft endcap SOMs through the property sheets. The zero axial coordinate is taken to be the intersection of the fore endcap and the main pressure hull shell.



Follow the Wizard to Input Bulkhead SOMs. The property sheet requires axial coordinate, thickness (axisymmetric analysis) and a material property identifier. The user enters these values in the property sheets. The sheet on the left is initiated by the Add Bulkhead button on the right property sheet. The material property is taken from a material property file.

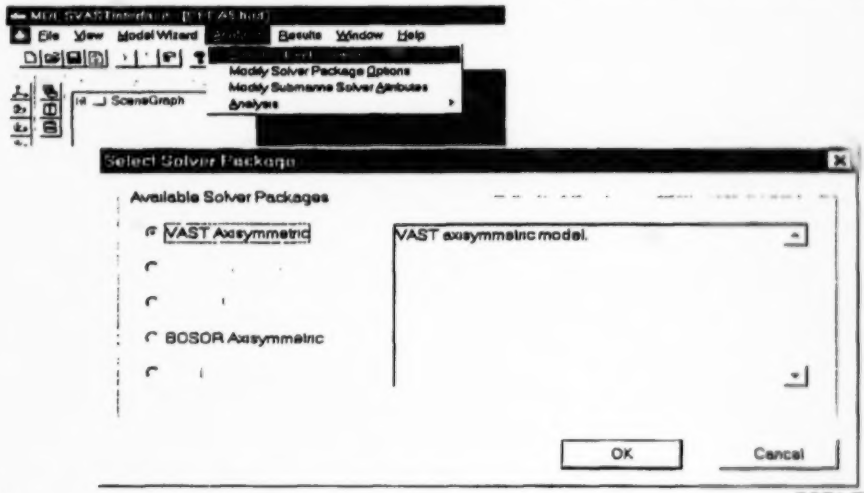


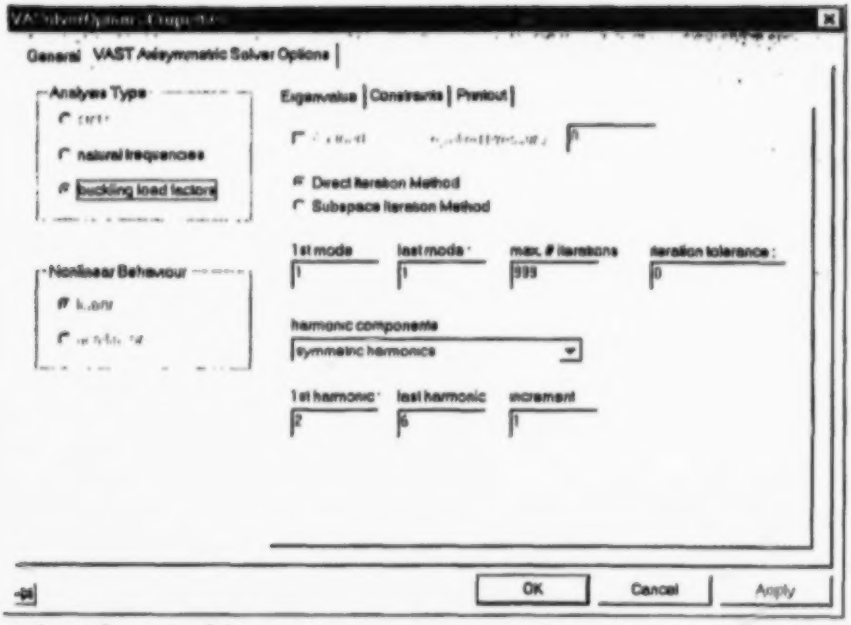


Axisymmetric and 3D Views of Geometry

Follow the Wizard to input stiffener SOMs through property sheets. Stiffener SOMs are input in groups (a group can be one stiffener) defined by a start axial location, a finish axial location, spacing and stiffener type. The stiffener type is accessed through a beam database. New stiffener groups need to be defined at changes in spacing or stiffener type. The geometry SOM data entry is finished by entering 'finish'. The completed axisymmetric geometric model is shown on the right of the previous figure in axisymmetric and 3D views.

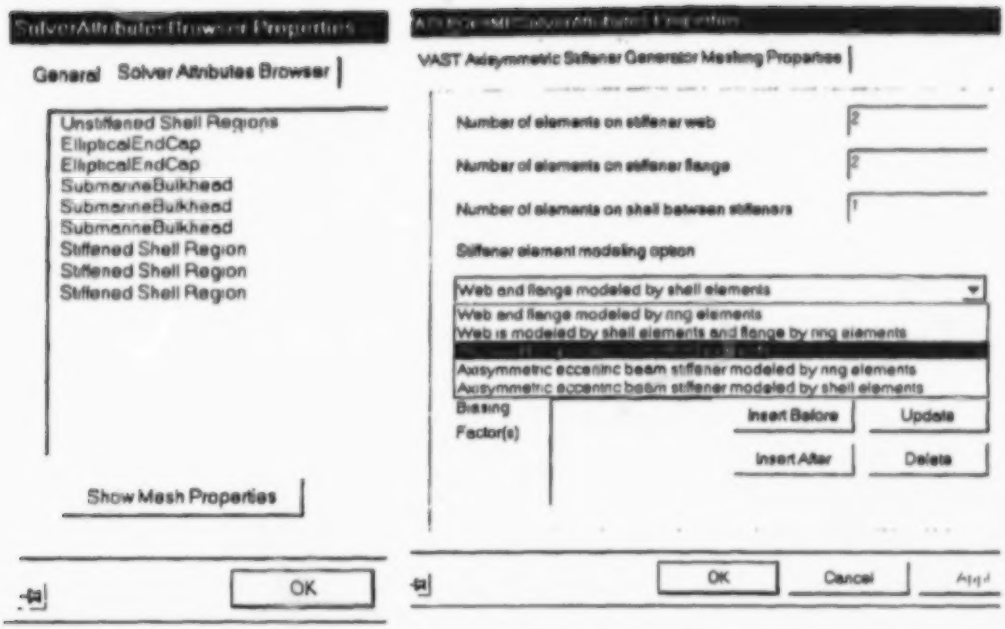
Once the geometry model has been created, it can be used to generate various types of analysis models. Phase 1 SubSAS allows only two analyses types at this time, either a BOSOR axisymmetric finite difference model and/or a VAST axisymmetric finite element model. The user selects the solver package from the analysis menu on the main tool bar.



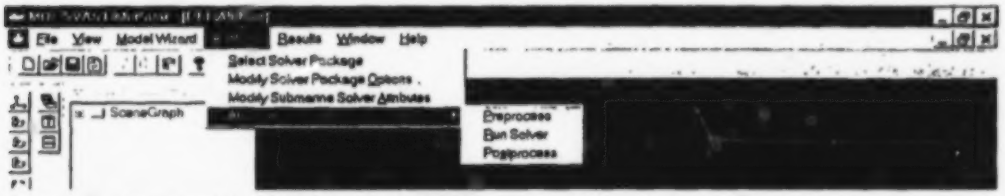


Property sheets for each of the analysis types appear once the analyses are chosen. This sheet is for VAST axisymmetric analysis. An axisymmetric buckling analysis has been chosen using the direct iteration eigenvalue method. Buckling shapes for axisymmetric analysis have two dimensions; the circumferential harmonic or wave number defined by Fourier component, and the longitudinal eigenvalue number or mode calculated from the finite element analysis. Input for the first and last longitudinal eigenvalue mode and the first and last circumferential harmonics to be calculated are required. The number of iterations and the solution tolerance per eigenvalue calculation can be entered or defaults can be used.

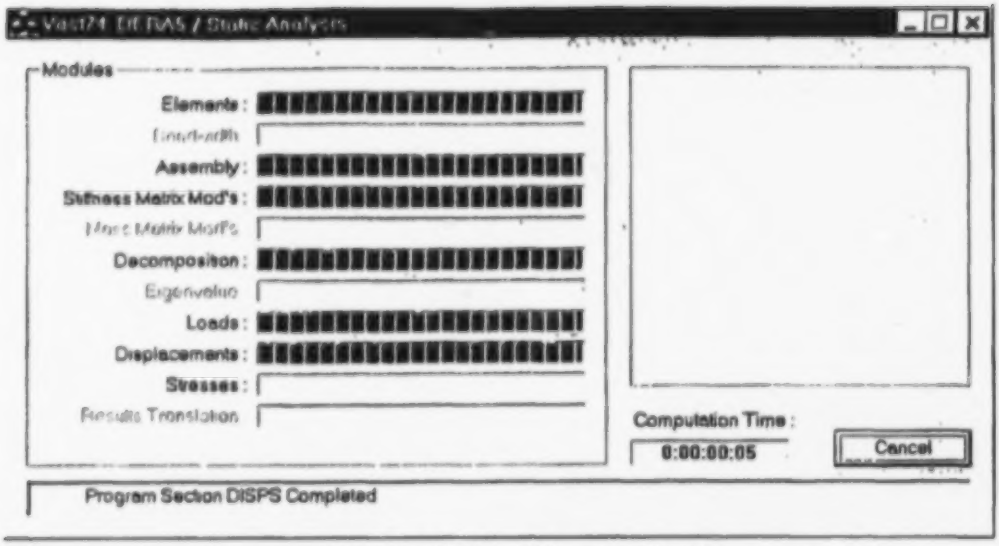
The constraints tab allows the user to enter the necessary constraints for the particular model and analysis. This step will be automated in phase 2 of SubSAS where appropriate constraints will be automatically selected with the option for the user to change them if desired. Constraints are necessary to prevent rigid body motion in numerical finite element models. For this example, a constraint was placed on the axial degree of freedom at the forward zero coordinate location.



The above figure shows the definition of the meshing parameters for the various SOMs through the Modify Submarine Solver Attributes button in the Analysis tool bar. In this example, one of the stiffener SOMs is being meshed. The choice of options for modelling stiffeners by the number of elements in the flange and web and on the shell between stiffeners and by either bar, beam, shell or combinations of elements is shown.



Once the solver model and analysis options have been defined, the user initiates the solver through the Analysis button on the main tool bar. In this case, the solver is broken up into three steps; preprocess which checks files and puts them in their final format, run solver and postprocess. Future versions of SubSAS will incorporate all three steps into one.



This screen shows the progress chart for VAST which automatically appears on the screen while the solver is running.

Finally, results of the analysis may be viewed as described above in the Presentation of Analysis Results section. Figures 10 and 11 are result displays from this example. Figure 10 shows the buckling eigenvalues as a function of circumferential wave number and Figure 11 shows one of the buckled mode shapes rendered in three-dimensions.

8. PLANS FOR PHASE 2 DEVELOPMENTS

Phase 2 developments are planned to incorporate items listed in the requirements section that have not been incorporated in the present phase 1 development of SubSAS. Funding for phase 2 is being sought from various sources. Specifically phase 2 will include:

- revision of phase 1 GUI to reflect user comments,
- creation of SOMs for three dimensional pressure hull geometry such as bulkheads and cutouts,
- creation of SOMs for secondary structure geometry such as decks, tanks, casings, tubes and towers,
- the ability to include out-of-circularity on the pressure hull shell and frames,
- inclusion of the classical analytical programs PRHDEF and SUBHUL,
- inclusion of the three-dimensional finite element models and analyses programs, including nonlinear finite element analysis and
- development of the post processing tools within the SubSAS system.

A third phase, which will extend the suite to other types of specialized loading, will be considered pending funding and requirements. This would probably include weapons load effects, ice penetration and seaway loads.

9. CONCLUDING REMARKS

This technical memorandum has presented the recent development of, and the future plans for, an efficient submarine structural analysis package entitled SubSAS (Submarine Structural Analysis Suite). The phase 1 developments of the program demonstrate that it can significantly reduce the time required for analysis by providing automated tools for the user to enter submarine geometry, produce various analysis models, undertake the analysis and view the results. The user also does not require detailed knowledge of the various analysis packages or their input files as this information is presented to the user with predetermined defaults suitable for most analyses. The user does have to have knowledge of submarine structures analysis. The efficiencies and automation have been realized through developing and using the modern object oriented programming tool, HOOD, to produce Smart Object Models of the various submarine structural entities.

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This technical memorandum describes the current development of, and future plans for, a common user interface which is being used to unite a suite of submarine structural analysis programs. The project is making use of object-oriented programming through DREA's HOOD TK (Hierarchical Object Oriented Developers Tool Kit) for the development and use of 'smart-object-models' (SOM) for submarine structure. The program allows the user to quickly generate a common database of axisymmetric and 3D pressure hull geometry SOMs. Pressure hull analysis programs will consist of linear axisymmetric analysis, analytical design-type equations, and linear and nonlinear 3D finite element analysis. The SOMs will have the ability to directly and quickly create appropriate input data files for these different analysis packages from the common pressure hull geometry database. A set of model checking and result visualization tools are also being developed to visualize buckling and vibration eigenvalues and mode shapes, displacements and stress contours.

This submarine structural analysis suite (SubSAS) will give engineers a tool for rapidly developing models and storing data for various types of analysis which may be required for design, acquisition and through-life support of submarines.

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